MAPPING URBAN LAND COVER FROM SPACE
SOME OBSERVATIONS FOR FUTURE PROGRESS

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Introduction

A definitive work on classifying land use and land cover from remotely sensed data is that by Anderson, Hardy, Roach, and Witmer (1976). They proposed a multilevel classification system since adopted by the U.S. Geological Survey for operational mapping of land use and land cover at Levels I and II (figure 1). The classes proposed have been compared with virtually every attempt since to classify land use and land cover with remotely sensed data.

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1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land

Figure 1

Most of the work on the USGS classification system predated knowledge of requirements necessary for attempting classification using digital data from Landsat. Though Landsat is refered to within the paper, the remotely sensed data used to define the mappable classes were hard-copy image products, typically aerial photographs, not digital data. Much effort and documentation has gone into demonstrating how Landsat digital data could be used to achieve USGS Level II classes. Some studies have shown how some of these efforts go beyond Level II, but little attention has been spent on explaining why certain Level II classes were not mapped adequately. It is just that type of knowledge that we need most, now that requirements for new sensing systems are being proposed. Perhaps a look at some of the successes and failures of mapping land cover from Landsat digital data and a look at the techniques used for image interpretation and their relationship to sensor parameters will give us a start in defining requirements for new sensors.

Experience With Landsat

When the first Earth resources satellite (Landsat-1) was launched 10 years ago, most investigators looked forward to interpreting the visual imagery reconstructed from data acquired by both the Return Beam Vidicon (RBV) and the more unfamiliar Multispectral Scanner (MSS). Interpreters had learned their trade using aerial photographs. The first Landsat images were interpreted in this way, and though the novelty of using data from space was exciting, the results for land cover mapping were disappointing. About all that could be discerned for urban areas were their locations indicated by areas on the images that had an "electric blue" color.

It was not until some researchers investigated the digital data that the "electric blue" areas were separated into some reasonable components. Residential areas were usually found to be separable from commercial or industrial areas. Parks, especially the distinctive golf courses used as control points, were separated quite clearly. Some transportation lines were picked up, not by distinctive classes, but as strings of "misclassified" pixels stretching across the urban fabric and extending into the countryside.

In using digital data these researchers were able to detect detail with the help of a computer that their colleagues couldn't make out in the fuzzy images they viewed and interpreted optically. They also used the computer's ability to deal with spectral data from four bands at once and separate multispectral classes from each other by statistical methods. But these advances, which have been responsible for the development of the field of digital image analysis, have tended to cut this breed of analyst off from the use of most of those elements of image interpretation developed over the years: size, shape, shadow, tone/color, texture, pattern, site, association, and resolution (Estes and others, 1975).

Most of the work in separating classes using the computer has been accomplished using tone/color. Results from defining and using texture as an interpretive element have been mixed, and thus the texture element is generally not used today except in special cases. Site has been an element used with increasing frequency, especially with the comparison of Landsat data with terrain, geologic, or soils data. It is only when the analyst takes manual control of the system and edits obvious errors in classification that he makes use of some of the remaining elements including not only site, but size, shape, pattern, and association.

So it is basically with only one interpretation element (color) and considerable assistance from the computer that digital image analysis has progressed. Interpretation in urban areas presents many difficulties; especially trying is the identification of the class <u>Residential</u>. Spectrally this class is exceedingly complex and close to signatures of many other classes. In low-density areas the Residential signature becomes confused with Brush, Agriculture, or Forestland. In high-density areas, it becomes confused with Commercial or Industrial. In spite of this difficulty, many have attempted to map sub-classes of residential: older, newer, dense, sparse, wooded, etc. The basic problem remains. Because of the diversity of man's dwelling habitat, it remains beyond the Landsat MSS's best attempts to map it adequately in all cases.

Most investigators have not tried to subdivide separate Commercial and Industrial classes. Though the USGS system recognizes the problem of separating these uses when they are intermixed, as in an industrial park, it does separate them in other cases. Working in a realm where it is not possible to see the details that aid interpretation like parking lots, railroad sidings, stockpiles of raw materials, etc., the digital data interpreter collects the pavement, concrete, and rooftop signatures together and presents us with a combined class. Even that degree of generalization is sometimes confused with Water, Shadow, Lava Flows, and Rangeland unless the analyst intervenes using some site or shape data he can process himself.

The Transportation class is even more elusive. In the USGS system includes communications and utilities and consists of major highways and railroads, airports, seaports, pumping stations, and power transmission substations. Included in this class are not only the characterizing feature, like an airport runway, but all the associated facilities like terminal buildings, parking lots, intervening land, and buffer zones. Any spectral class could conceivably belong in this group. The Transportation class is interpreted from photographs using size, shape, pattern, site, and association with frequent assists from supplemental data for confirmation. About the most the digital analysts can point to are linear associations of residential pixels out in the country that define an interstate highway or the commercial-industrial pixels that cover a runway.

The Other Urban or Built-up Land class usually has the same signature as grass and barren land classes. The latter two classes are usually not changed to the Other Urban class within the urban area as the USGS system requires. Instead, most maps from analysis of digital data have rangeland and agricultural pixels peppering the urban area. Some components of this class such as zoos, waste dumps, spillways, and ski areas are usually missed altogether.

To sum up, though many have tried, none have succeeded in meeting the requirements for USGS Level II classes in urban areas using Landsat digital data. The use of digital data has produced mixed results when compared to photo-interpretation of the visual imagery, and interpretation has proceeded using relatively few of the elements of image interpretation.

Requirements For Mapping Levels II and III

Cognizant of the difficulties faced in mapping Level II classes, we shall proceed into the more speculative realm of Level III. USGS Professional Paper 964 leaves development of Level III to interested users motivated by their particular needs. Some of those users have responded with Level III classification criteria. The U.S. Geological Survey conducted a demonstration project with highly urbanized San Mateo County and produced land use and land cover maps of the county to Level III at 1:24,000 scale. The classes that were mapped at this level within the Urban and Built-up Level I class are listed in figure 2 and used as examples in the following discussion.

11 Residential	111	1 or less units/hectare
	112	2 to 8 units/hectare
	113	9 or more units/hectare
12 Commercial and Services	121	retail and wholesale
	122	commercial outdoor recreation
	123	educational
	124	hospital, rehabilitation or other public
	125	military
	126	other public
	127	research centers
13 Industrial	131	heavy industrial
	132	light industrial
14 Transportation, Communications, and Utilities	141	highway
	142	railway
	143	airport
	144	port facility
	145	power line
	146	sewage
15 Industrial and Commercial Complexes		
16 Mixed Urban or Built-up Land		
17 Other Urban or Built-up Land	171	extensive recreation
	172	cemetery
	173	parts
	174	open space/urban

Figure 2

Density of dwelling units was the criterion used for subdividing the Residential class. Some density information can be inferred from examination of the spectral ranges of residential pixels, but this has been an imperfect method owing to natural diversity of basic cover types that are integrated within the pixel. Increased resolution should add to the ability of measuring density through signature analysis, but at some point pixels will be focussed on individual basic land covers like rooftops, pavement, grass, and trees. Research should be done to determine the effect differing resolutions have on being able to map residential density using spectral information alone, using spectral and textural, and using spectral, textural, and association. Interpretation using the latter techniques should be done both digitally and visually.

It should be realized that although increased resolution should improve the ability to map residential density, it will also demand more sophisticated digital techniques. A photo-interpreter does not have to be taught how to use the technique of association. He only needs an image sharp enough to recognize the basic land cover features and his experience in knowing how these features relate to one another in the landscape. Making good use of improved resolution within the digital domain so we can maintain the advantages digital data have demonstrated will be a large challenge that will be assisted by findings in the fields of cybernetics, robotics, and machine intelligence. Some attention should be directed towards applying findings from that body of experience towards making our pattern-recognition algorithms smarter.

Separation of commercial from industrial uses will be the most difficult to achieve with imagery alone. Identification is possible now only because of the ability of a photointerpreter to identify objects using size, shape, and site. Piles of raw materials, smokestacks, or railroad sidings are first noticed and then used to recognize several buildings and intervening land as a factory through association. Resolution has to be sufficient to recognize those related features, but, even with the very best resolution, digital techniques for processing those data falls short of the ability of the photointerpreter. Some simple models could be devised to recognize certain feature types, however. One might teach the computer to recognize some types of commercial by classifying all buildings directly fronting on the street (if one could separate the building from the street). Or a more complex discrimination could be attempted. The building separated from the street by pavement or concrete (probably seen spectrally as a bulge in the street) and occupied by parked cars during a weekend pass of the satellite could be assumed to be commercial as well.

Perhaps a more fruitful technique lay in utilizing supplemental data such as zoning maps in a layered classifier. This supplemental data will be more important as one dips down into Level III so we may as well use them as soon as possible. There comes a point when it becomes academic to design a Rube Goldberg mechanism for discriminating a shopping center from an electronics research facility when everyone in town knows which is which and when they've been on maps for years. Our challenge is in efficiently utilizing all the data available in characterizing the landscape not in making more work for ourselves.

The Transportation classes generally can most readily be recognized by shape as linear features. Classification by that criterion has been hampered so far by breaks in the linear pattern, characteristic of coarse resolution. Research should be done into seeing the effect that different resolutions have on the continuity of highways, railways, and power lines of varying widths and in designing algorithms to recognize these features. Once identified, it should be possible to separate types of transportation from one another by spectral data. Association will be needed to group related buildings and land into the functional class Transportation, Communications, and Utilities described by Anderson. Here again, we should not overlook the use of existing maps and data to make our job much easier.

The Other Urban or Built-up class consists mostly of non-urban covers in an urban setting. This is mapped fairly well now though most do not bother to stratify this class from the non-urban agricultural and forest land classes. The real challenge here with increased resolution is going to be in separating grass and trees that are part of the fabric of residential neighborhoods and some commercial industrial areas from parks and vacant land. One might even imagine a case where maximum resolution is used to define classes like Residential, Commercial, Industrial, and Transportation using all the techniques available and then degrading the resolution so only open space above certain minimums gets called out separately.

Other Considerations

With discussion of Other Urban or Built-up we get close to some fundamental questions that will be confronting us as we attempt to map Levels II and III with remotely sensed data. At what point does a street become Transportation and cease to be part of the surrounding Commercial class? When is a low-density residential area considered open space? Are we mapping the landscape as it is or as we imagine it? Can we even agree on how it really is?

Different users will have different ideas about how it should be done. Planners usually see the world in parcels and as it appears on zoning maps. A park isn't a park unless it has a sign proclaiming its existence. A stream valley containing residential lots backed up to it will not exist as open space if the property line runs all the way down hill, but will be proclaimed as open space if property lines stop short of the stream channel.

Others who may use maps developed from remote sensing in urban areas will see the world quite differently. Someone interested in assessing potential energy use may want to map every building separated by function and may appreciate a thermal look at night to assess heat loss. Someone looking at solar energy potential will be interested in similar classes but will have an additional interest in topography and orientation to the sun. Urban hydrologists are going to be concerned with the amount and dispersion of basic land cover types as they differ in their permeability characteristics. Demographers are going to want to know residential density and relationship to enumerated districts. Everyone is going to want to look at change.

We have discussed the successes and failures of mapping land cover with the present Landsat multispectral scanner and have presented some ideas on how Level II and Level III class discrimination might be improved with data of higher resolution and more sophisticated interpretation methods. There has been one underlying assumption. When multispectral data collected from space have resolution sharp enough to photointerpret, that tried and true method can be used to map all classes mappable from remotely sensed data. Since the art of photointerpretation is likely to flourish with the advent of higher resolution data from space, at least until more sophisticated digital techniques are developed, more research should be done to determine quality of photointerpretation of multispectral data of various resolutions.

Throughout this discussion, resolution has been the sensor characteristic judged to be most critical for urban applications. There is general agreement with the recommendations of the Land Resources Panel of the Multispectral Resource Sampler Workshop (ORI, 1979) with the additional point that while increased resolution will always help the photointerpreter do a better job, it will not really help, and may even hinder, the digital analyst until more sophisticated elements of interpretation are developed. Much information on urban morphology needs to be collected and utilized in interpretation models that include site and association factors.

This is not to imply that other sensor characteristics are unimportant for urban applications. Almost surely data in the blue and thermal bands will be of help in discriminating hard surface materials and in separating urban from non-urban. Unfortunately, the intense work that has been done in examining spectral responses for agricultural, natural vegetation, and geologic applications has not been accomplished adequately in an urban setting. While urban targets are made up of some of the basic land covers that have been studied, some special attention should be paid to examining the characteristics of these in an urban setting.

Much less is really known about the effects of bandwidth or quantization levels for urban applications. Again, urban applications can learn from the findings of others on these effects, but some experiments using urban test sites would be most desirable in strengthening overall conclusions.

Conclusion

So it comes down to two overriding considerations, resolution and more sophisticated analysis techniques. Much progress has been made in studying the urban environment from space, but much work remains. For digital data from spacecraft sensors to have a great impact on urban studies, data of higher resolution must be acquired, and analysis techniques must be developed to utilize them in ways analogous to the art of the photointerpreter.

References

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